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Setting seismic input characteristics required for designing

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Abstract. The paper is devoted to the analysis of seismic input characteristics from the point of view of their importance for engineers. It is noted that the design input does not need to have an external resemblance to the real one but it must provide for some properties of real actions. The paper considers three groups of seismic input characteristics: kinematic, spectral and energy ones. The stability of the characteristics under consideration is analyzed within the seismic intensity on the MSK scale. Among all characteristics, peak acceleration, peak velocity, harmonicity coefficient, Arias intensity, and absolute cumulative velocity are highlighted. It is noted that the kinematic characteristics significantly depend on the prevailing accelerogram period, and many energy characteristics are stable within the seismic intensity under consideration and can describe it. It is noted that for calculating structures under the design earthquake action, the kinematic characteristics should be fundamental for the engineer, and for calculating structures under the destructive (maximum design) earthquake action, the energy characteristics are fundamental. Two new seismic input characteristics are introduced, which are based on the response spectrum of the work of plastic deformation forces and on the structure damage spectrum.

1. Introduction

Using certain models of seismic input is widely discussed in literature [1–11].

When selecting seismic input models, different authors considered to various characteristics of real actions.

According to widespread opinion, it is the necessary to use a package of past earthquake accelerograms. It is supposed that this way makes it needless to study the properties of seismic effects that define the structure behavior under seismic actions. Hazardous input is assumed to be found in the packet under consideration and if you get a lot of real actions from different places, it is most likely to be there. However, in practice the design action package includes about 60–100 accelerograms and sometimes less, which is not enough, which is a significant drawback of this way. You can get 100 high-frequency accelerograms and draw a wrong conclusion about the high seismic resistance of a weakly damped seismically insulated structure. Therefore, selecting past earthquake accelerograms must be carried out together with engineers, who know what is dangerous for their constructions.

Another, less important, but also significant drawback of this approach is an enormous amount of necessary calculations, though not more than 2–3 inputs from the accelerogram package turn out dangerous. Calculating the structure using other accelerograms will be "redundant." Hence, attempts to specify a limited number of design inputs that should simulate real ones are made. In so doing, the central question to answer is the question of what properties of real actions should be taken into account when modeling design input. In our opinion, we do not have to "copy" the real earthquake functions, but it is necessary to mark out the main features of real actions and to take these features into account in the process of generating input. Such approach has been in fact developed in earthquake engineering over the past 60 years.

The first experts in earthquake engineering used harmonics as an action model.

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The founders of modern earthquake engineering in the USSR used the action model in the form of a damped sinusoid. Furthermore, complex models were used in the form of Berlage polynomial, Puzyrev polynomial, Gelfand polynomial and polynomial proposed by N. Ricker [12].

These models based primarily on specifying peak ground accelerations (PGA) and possible action frequency. In most cases, the authors analyzed the base acceleration, not paying attention to the displacements, so many input processes, except the Berlage polynomial, were unbalanced and led to huge displacements. The second feature of most processes is that all processes are narrowband, i.e. one frequency is dominant.

Working with a linear system, when the system spectrum is known, several narrow-band processes can be used. To use one process, a number of experts proposed a variable frequency input models. They believed that such processes would be broadband. This result is described in some Russian textbooks: the authors showed that they provide only PGA of real actions and do not estimate displacements.

In [9] it was proposed to use well-known models of accelerograms to describe velocigrams. Then the processes become balanced, i.e. the velocity at the end of the process becomes 0, and the residual displacements are limited. However, the processes under consideration are still quite narrowband. As an example, the acceleration spectrum of the Annaev – Uzdin process [9] is given in Fig.1. Accelerograms, seismograms, and characteristics of models are shown above in Tables 1-3.

Table 1. Unbalanced processes.

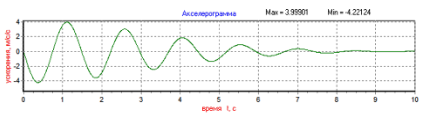
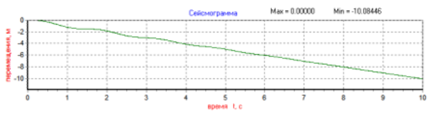
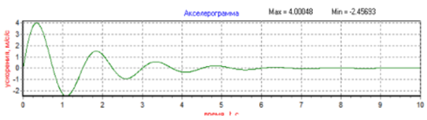
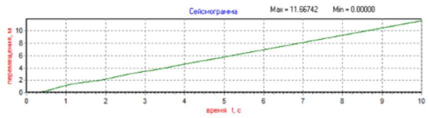
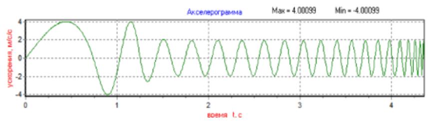
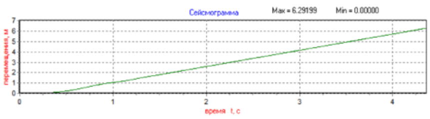
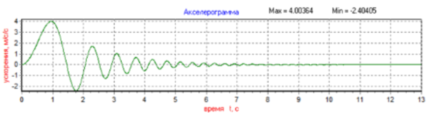
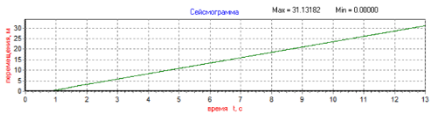
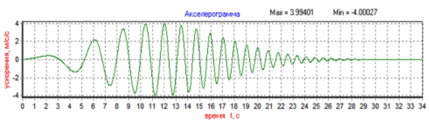
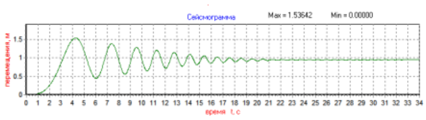
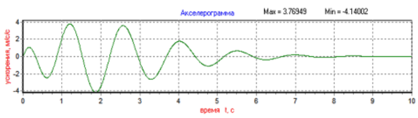
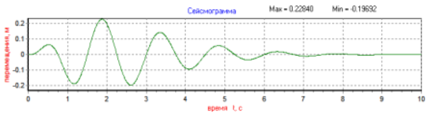
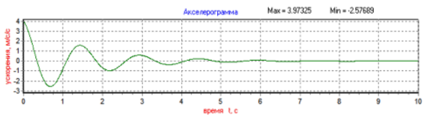
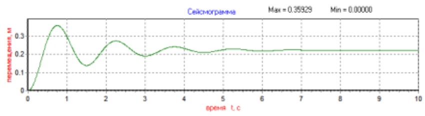
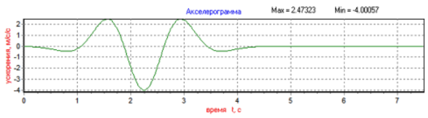
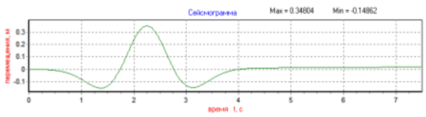
№	Model name	Model accelerogram	Model seismogram
1	Gelfand's model		
2	Korchinsky's model		
3	Kostyrev-Vetoshkin's model		
4	Epstein's model		

Table 2. Balanced processes.

№	Model name	Model accelerogram	Model seismogram
5	Annaev-Uzdin's model		
6	Berlage's model		
7	Velocity, presented by damped sinusoid		
8	Ricker's model		

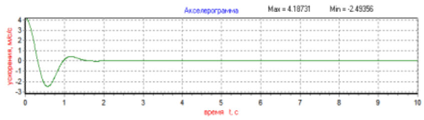
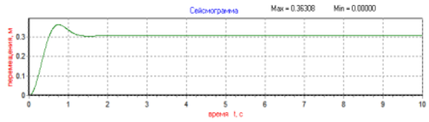
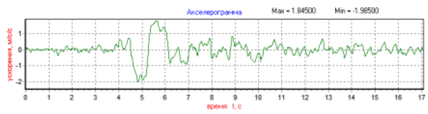
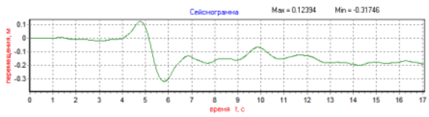
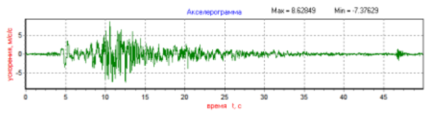
№	Model name	Model accelerogram	Model seismogram
9	Puzyrev's model		
10	Bucharest earthquake		
11	Tabass earthquake		

Table 3. Characteristics of processes.

№	Model name	Model function	PGA, m/s^2	PGV, m/s	I_A, m/s	CAV, m/s	κ
1	Gelfand's model	$y=e^{-\beta\cdot t^2}\cdot\sin(\omega\cdot t)$	4.22	1.99	4.08	10.76	10.75
2	Korchinsky's model	$\ddot{y}=e^{-\beta\cdot t}\cdot\sin(\omega\cdot t)$	4.00	1.84	1.52	4.86	13.19
3	Kostyrev-Vetoshkin's model	Discrete input	4.00	1.91	2.59	7.11	6.88
4	Epstein's model	$\ddot{y}=A\cdot e^{-\beta\cdot t}\cdot\sin(\omega(t)\cdot t)$	4.00	3.14	2.05	6.00	12.62
5	Annaev-Uzdin's model	$\dot{y}=A\cdot e^{-\beta\cdot t}\cdot\sin(\omega(t)\cdot t)$	4.00	1.14	11.99	33.07	4.76
6	Berlage's model	$y=t^n\cdot e^{-\beta\cdot t}\cdot\sin(\omega\cdot t)$	4.14	0.93	3.43	9.37	1.10
7	Velocity, presented by damped sinusoid	$\dot{y}=e^{-\beta\cdot t}\cdot\sin(\omega\cdot t)$	3.97	0.76	0.99	3.92	2.50
8	Ricker's model	$y=\left(1-2\cdot\left(\omega\cdot\left(t-\frac{\pi}{\omega}\right)\right)^2\right)\cdot e^{-\left(\omega\left(t-\frac{\pi}{\omega}\right)\right)^2}$	4	0.93	1.68	4.74	1.6
9	Puzyrev's model	$y=e^{-\left(\frac{\omega}{\pi}\cdot t\right)^2}\cdot\sin(\omega\cdot t)$	4.19	0.81	0.73	1.93	2.31
10	Bucharest earthquake	Discrete input	1.99	0.80	0.74	5.48	1.04
11	Tabass earthquake	Discrete input	8.63	1.00	11.20	33.30	3.29

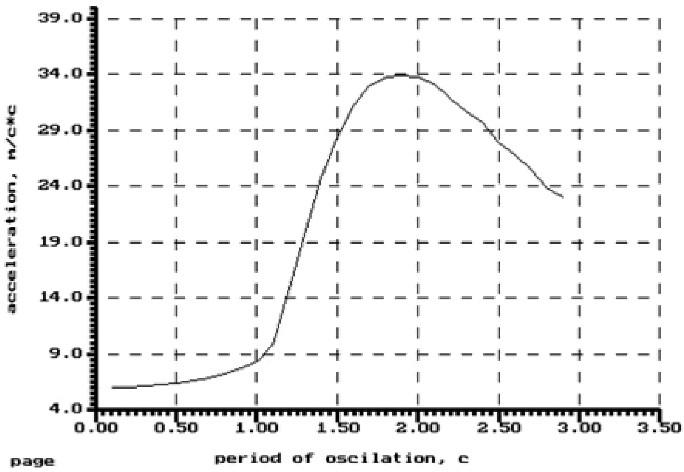


Figure 1. The acceleration spectrum of the Annaev – Uzdin process [9].

Thus, engineers are faced with many models of seismic actions with the same PGA and similar frequencies. In order to give preference to one or another model, it is necessary to know characteristic properties of real actions and the influence of these properties on the behavior of structures during earthquakes. A lot of various characteristics of seismic actions are discussed in literature. Among the most famous ones, in addition to peak accelerations (PGA) one can include the following:

1. Harmonic coefficient

$$\kappa = \frac{\ddot{y}_0^{(\max)} \cdot y_0^{(\max)}}{\left(\dot{y}_0^{(\max)}\right)^2}, \tag{1}$$

where $\ddot{y}_0^{(\max)}$ is the peak acceleration value (PGA); $\dot{y}_0^{(\max)}$ is peak velocity value (PGV); $y_0^{(\max)}$ is peak desplacement value (PGD).

2. Arias intensity I_A and Arias modified intensity I'_A [14], as well as modifications of this intensity [15] $I_{A,std}$ and $I'_{A,std}$:

$$I_A = \frac{\pi}{2 \cdot g} \int_0^{\tau} \ddot{y}^2(t) dt; \tag{2}$$

$$I'_A = \int_0^{\tau} \ddot{y}_0(t)^2 dt \tag{3}$$

where $\ddot{y}_0(t)$ is the earthquake accelerogram, τ is its duration.

Note that the Arias intensity has the dimension of velocity.

3. Absolute cumulative velocity, CAV [15]

$$CAV = \int_0^{\tau} |\ddot{y}| dt \tag{4}$$

4. Potential damage index I_{Araya} proposed by R. Araya and widely used to describe seismic impact intensity [16, 17]:

$$I_{Araya} = \frac{I'_A}{{\nu_0}^2}, \tag{5}$$

where ν is the number of crossing of the time-axe by the process

5. Effective earthquake duration

$$\tau = 2\sqrt{\frac{\int_0^{t_s} (t - t_c)^2 a^2(t) dt}{\int_0^{t_s} \ddot{y}^2(t) dt}} \tag{6}$$

where t_c is the “center of acceleration gravity” along the time axis, t_s is the total accelerogram duration.

6. Root-mean-square (RMS) peak acceleration [18]

$$\sigma_A = \sqrt{\frac{\int_0^{\tau} \ddot{y}_0^2 dt}{\tau}} = \sqrt{\frac{I_{A,\mathrm{mod}}}{\tau}} \tag{7}$$

7. Seismic energy density, SED [13]

$$SED = \int_0^{\tau} \dot{y}^2(t)dt\,; \tag{8}$$

8. RMS peak velocity [18]

$$\sigma_V = \sqrt{\frac{\int_0^{\tau} \dot{y}_0^2 dt}{\tau}} = \sqrt{\frac{SED}{\tau}} \tag{9}$$

These characteristics (except for the harmonic coefficient) are often called energy. Recently, many experts [15] prefer to use the CAV value as an indicator of earthquake intensity.

Tables 1.2 show frequently used seismic input models normalized to 4 m/s^2 and the values of some characteristics of these models. For comparison, Table 2 shows two accelerograms of real impacts of 9 degree on the MSK-scale (Bucharest and Tabas). As can be seen from Table 1, most of the known processes are unbalanced. The harmony indicators of unbalanced processes turn out to be unrealistic due to large parasitic displacements of the process. For processes in which a velocigram is adopted as a basic function, the process is balanced, but at the same time $\ddot{y}_0(0) \neq 0$.

The purpose of this paper is to systematize the known characteristics, consider new indicators of the earthquake intensity, as well as to analyze the significance of the considered parameters when setting design accelerograms.

2. Methods

2.1. Determining the main characteristics of seismic input necessary for an engineer in designing

Some characteristics of seismic input have been considered earlier. In the general case, all characteristics can be divided into three groups: kinematic, spectral and energy ones.

Kinematic characteristics include

- peak ground acceleration (PGA);
- peak ground velocity (PGV);
- peak ground displacement (PGD);
- the harmonic coefficient κ, calculated by the formula (1);
- seismic action duration τ.

The main spectral characteristics are acceleration, velocity and displacement spectra, as well as the Fourier spectra of seismic actions [19]. In addition to these characteristics, the prevailing action period T or the prevailing action frequency ω can be specified. However, it should be borne in mind that these values are different for an accelerogram and a seismogram.

The energy input characteristics are quite diverse. We consider it necessary to mark out the following:

- Arias intensity, I_A, determined by formula (2);
- seismic energy density SED (formula (8)) and the associated root-mean-square velocity σ_V (formula (9));
- absolute cumulative velocity CAV (formula (4));
- the work of plastic deformation forces PFW, when an earthquake acts on an elastoplastic pendulum

$$PWF = \int_0^{\tau_{eq}} (R(y, \dot{y}) \cdot \dot{y})dt\,, \tag{10}$$

In formula (10), $y(t)$ is pendulum displacement, $R(y, \dot{y})$ is pendulum response to seismic action.

Now the PGA mainly used in engineering calculations. The PGD value becomes necessary to be additionally used in calculating bridges to estimate the movable bearing travel [20]. Other action characteristics are used in generating design accelerograms [21].

Specifying action characteristics correctly seems to be very important and this question is still far from being sold finally. However, results obtained on questions of specifying these characteristics should be taken into account in calculations.

First, the PGA decreases with increasing the prevailing action period. Prof. O.A.Savinov drew attention to this phenomenon. The data on this question are given in the monograph [20]. A.A. Dolgaya obtained the dependence of the PGA on the earthquake prevailing period T_{eq} based on the records of 240 earthquakes with intensity 8 on the MSK-scale [7]. The corresponding dependence is shown in Fig. 1. Further, such dependence was confirmed in the analysis of about 100 records of earthquakes with intensity 9 on the MSK-scale [28, 29].

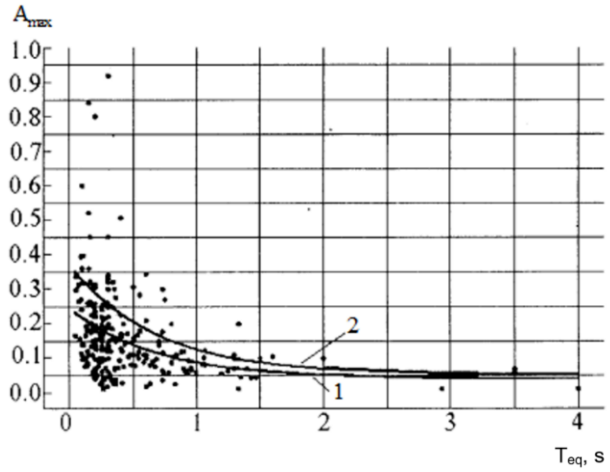


Figure 2. Regression dependencies (for I = 8 on the MSK-scale).
1 – $\bar{A}_{\max}(T_з)$; 2 – $\bar{A}_{\max}(T_з)+\sigma_A(T_з)$.

Secondly, such an important indicator as the harmonic coefficient, just like the PGA, depends on the prevailing action period. In the Guidelines for calculating nuclear power plants (USA), this coefficient is recommended to be set equal to 5 [23]. In 2000 A.A. Dolgaya and O.A. Sakharov [11] found the dependence $\kappa(T_{eq})$. In later studies [28, 29] this dependence was confirmed. Fig. 2 shows such a dependence according to [29].

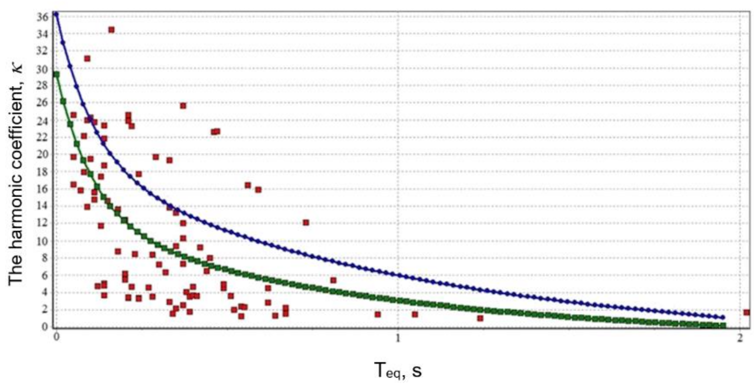


Figure 3. Dependence of the harmonic coefficient κ on the prevailing input period T_{eq}.

Thirdly, energy characteristics may also depend on the prevailing action period. Studies available [22, 24] show that the Arias intensity and the CAV are independent of the prevailing period of action on the accelerogram. This allows one to use them as a universal action characteristic. In particular, the USA experts analyzed more than 500 earthquakes recorded in the USA and came to the conclusion that the most stable energy action characteristic is the CAV value [15]. The values of the I_A value for earthquakes of intensity 9 on the MSK-scale for different exceedance probability P are shown in Table 4.

Table 4. The Arias intensity values of a given exceedance probability.

I_A values depending on the probability of their exceeding			
P, %	70	80	90
I_A	42.528	52.601	68.389

2.2. Additional characteristics of seismic input important in multi-level designing

In our opinion, the characteristics considered poorly describe the strong earthquake intensity. The intensity of destructive earthquakes is determined by the degree of building and structures damages. Generally in order to damage the structure, it is necessary to do some mechanical work and to do this, it is necessary to have energy. For this reason, the above-mentioned energy action characteristics were introduced. They indirectly characterize the energy transmitted by the earthquake to the structure. In the literature attempts to link energy with the mentioned characteristics [13].

However, these attempts give very rough estimates of energy transmitted by the earthquake to the structure. In this regard, the authors tried to introduce additional action characteristics directly related to the energy and structure damage. For this, we considered two models of structure damage accumulation. The first model is elastoplastic, and the second is adaptive with degrading stiffness.

In the first case, an elastoplastic pendulum with a Prandtl diagram is considered (Fig. 4). The diagram is characterized by the inclination angle α for the first section of the diagram and by the elastic limit F_{el} with the ultimate displacement u_{el}. The rigidity of the system is $C = tg\alpha$, and the oscillation period in the absence of sliding is $T = 2\pi / k$; where $k^2 = C / m$; m is the system mass; the elastic limit is conveniently expressed in terms of the conditional coefficient of friction $f = F_{el} / (m \cdot g)$. During the loading process, the forces of plastic deformation work only in the second section of the diagram.

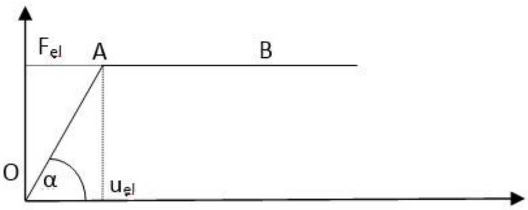


Figure 4. Diagram "force-displacement" of the system used for assessing the earthquake intensity.

To construct the spectrum of the work of plastic deformation forces *W(T)*, we consider the equations

1. for the OA section

$$\ddot{y} + \gamma \cdot k \cdot \dot{y} + k^2 \cdot y = -\ddot{y}_o \qquad (11)$$

2. for the AB section

$$\ddot{y} + g \cdot f \cdot \mathrm{s}ign(\dot{y}) = -\ddot{y}_o \qquad (12)$$

Equation (11) includes the force of internal friction in the material, characterized by the coefficient of inelastic resistance γ. The value of γ influences the value of *W*. For objects of mass building constructions, the value of γ varies from 0.08 to 0.2. The lower boundary refers to metal and monolithic reinforced concrete structures on rocky soils. The upper boundary refers to rigid structures on highly compressible soils. To assess the strength of the earthquake, the authors propose using a representative structure with $\gamma = 0.1$.

Solutions of equations (11, 12) have a standard form and are written analytically within the frame of an integration step. Integration begins at the OA section (equation 10), and the transition to the AB section occurs if the elastic force C_y exceeds the elastic limit F_{el}. The return from section AB to section OA occurs when the sign of the mass velocity relative to the base changes. Fig. 5 and 6 show accelerograms of two earthquakes: Bucharest (1977) and Tabass (1978). Earthquakes intensity for both earthquakes is equal to 9 on the MSK scale, but they have completely different characteristics. These characteristics are shown in Table 4. In addition to the characteristics noted above, a harmonic index is included in Table 4.

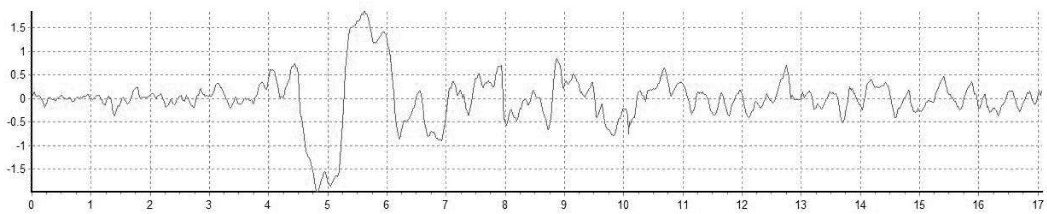


Figure 5. Accelerogram of Bucharest (1977) earthquake.

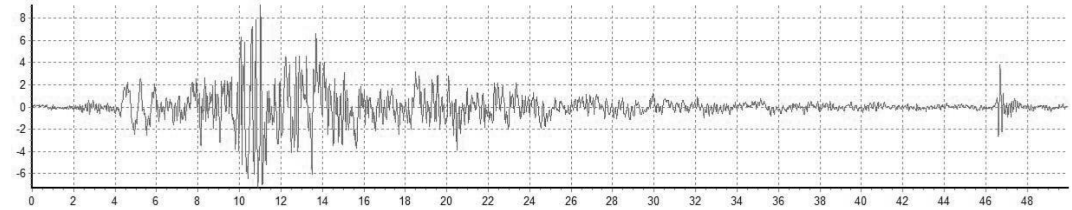


Figure 6. Accelerogram of Tabass (1978) earthquake.

Table 5. Characteristics of Bucharest (1977) and Tabass (1978) earthquakes.

	PGA, $\ddot{y}_o$, m/s²	Arias intensity I_A, m/s	Absolute cumulative velocity, CAV, m/s	Harmonic index, κ
Bucharest earthquake	2	0.74	5.48	1.035
Tabass earthquake	8.63	11.2	33.3	3.286

The spectra of plastic deformation forces for the two considered earthquakes are shown in Fig. 7, 8. With large differences in the seismic impact characteristics used, the $W(T)$ dependences for the considered earthquakes turn out to be close.

Figure 7. The spectrum of the work of plastic deformation forces for the Bucharest earthquake with a peak acceleration equal to 0.2 g, $\gamma = 0.1$.

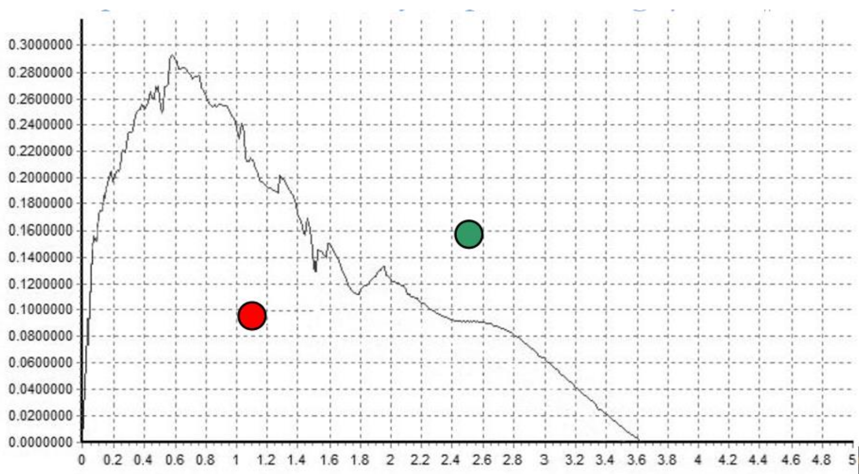


Figure 8. The spectrum of the work of plastic deformation forces for the Tabas earthquake with a peak acceleration equal to 0.863 g, $\gamma = 0.1$. The red and green dots indicate the possible values of the monotonous loading in emergency (red dot) and admissible (green dot) cases.

The work of plastic deformation forces does not depend only on the system oscillations period, but also on its elastic limit F_{el}. In order to assess the possible earthquake potential, it is necessary to find a structure that the earthquake can destroy. To do this, the dependences $W(T)$ should be constructed for various characteristics f. In the general case, one should work with the two-dimensional spectrum $W(T, f)$. Fig. 9 shows such a two-dimensional dependence for the El Centro earthquake in isoclines.

The potential destructive ability of an earthquake can be estimated by the volume of the figure formed by the surface $W(T, f)$. If we designate this indicator as PFW (Plastic forces work), we can write:

$$PFW = \int_0^{T_{max}} \int_0^{f_{max}} W(T, f)dfdT \quad (13)$$

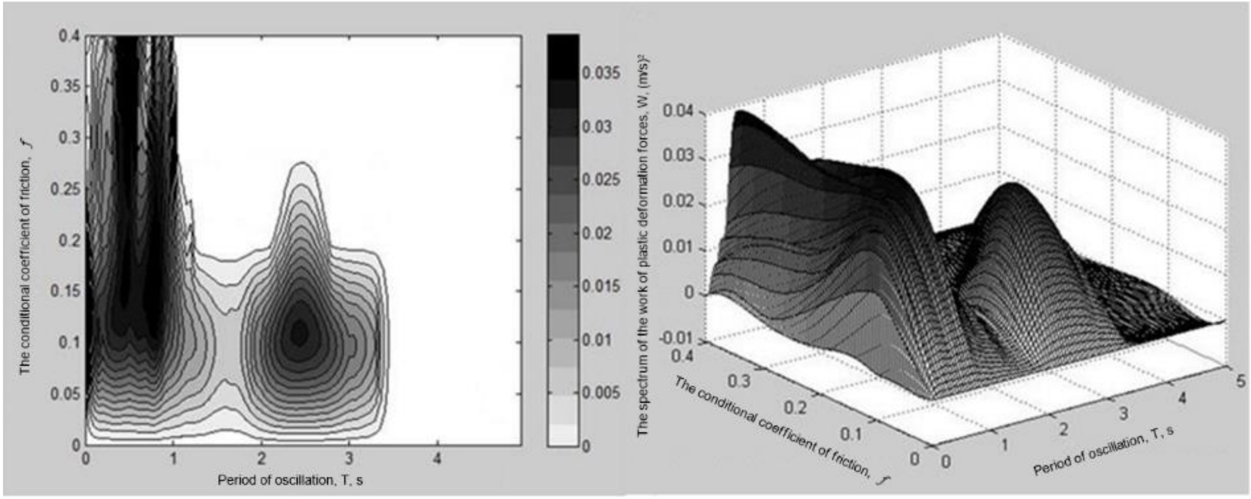


Figure 9. A two-dimensional dependence for the El Centro earthquake in isoclines.

The proposed indicator for assessing earthquake intensity reflects the physical meaning of a macroseismic damage analysis and does not require any expert agreement about the earthquake duration. Singling “safe” sections out of the earthquake process occurs automatically depending on the structure properties. In addition, the proposed indicator gives more information about the earthquake than a macroseismic analysis. For example, a high-frequency earthquake in a territory built up with flexible structures does not result in a large amount of damages and is characterized as weak or moderate. At the same time, in the territory built up with low-rise rigid buildings, the same earthquake would cause a large amount of damage and must be described as strong. When using the proposed indicator of the earthquake intensity is used, the earthquake itself will find objects that it can destroy, which makes it possible to evaluate its strength objectively.

The proposed criterion is conveniently used in assessing the earthquake resistance of structures under strong impacts in accordance with [25].

To this end, the point of monotonous destruction of the structure under consideration is put on the spectrum of work of the forces of plastic deformation. If the point is inside the graph (red dot in Fig. 7), the system will collapse due to low-cycle fatigue or progressive collapse. Otherwise, (green dot in Fig. 7) the system will adapt to the loading program.

For adaptive systems with degrading stiffness, as a criterion for damage accumulation (earthquake intensity), one can use the damage index χ and the current period of the structure fundamental vibration tone T. It is assumed that as the damage accumulates, the rigidity of the system will decrease, and the period of the fundamental vibration tone will increase. At the time of collapse, the rigidity comes down to 0. The concept of damage was introduced by L.M. Kachanov [29] and Yu.N. Robotnov [30] and is characterized by the area of the cross-section part occupied by the crack. At the beginning of the oscillations $\chi = 0$, and at the time of collapse $\chi = 1$.

To describe the structure behavior, the authors used the Kirikov – Amankulov model of the damage accumulation [31]. In accordance with this model, the damage index χ increases linearly, and the oscillation period decreases linearly with an increase of the maximum system displacement u_{max} over the loading history.

For this type of damage accumulation, the restoring force is described by the equation

$$R(y) = \frac{r(u)y}{1 + \kappa(u)y^2} \quad (14)$$

where y is the structure displacement; u is the maximum structure displacement over the history of loading; κ is the nonlinearity parameter.

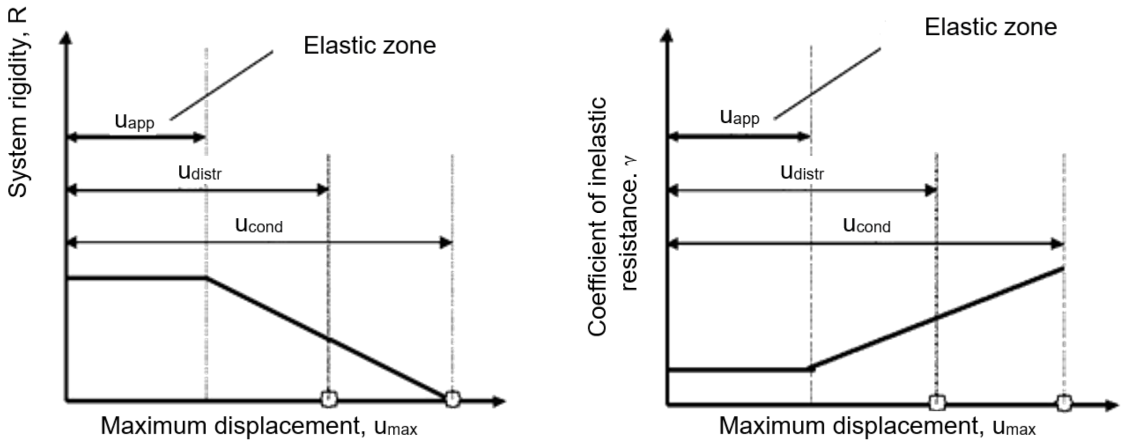
The system rigidity is constant until the displacement u is less than the elastic limit u_{app}. When the elastic limit is exceeded, the stiffness begins to fall linearly with an increase of the maximum value of the system displacement over the loading process history. The displacement corresponding to the zero rigidity of the system is called the conditional displacement of destruction u_{cond}. In fact, the displacement at which the destruction of the structure takes place is considered the displacement u_{distr} at which the reaction of the system reaches its maximum value. The dependences $R(u)$ and $\gamma(u)$ are shown in Fig. 9.

Systems with the type of nonlinearity under consideration are among the adaptive systems that, due to the increase of damages, are detuned from resonance. Ya.M. Eisenberg introduced the concept of a system state spectrum [31] for such structures. The system adapts itself to the loading program if the state spectrum crosses the response spectrum at some point.

Oscillations of a system with degrading rigidity are described by the equation:

$$m\ddot{u}+\gamma\sqrt{rm}\dot{u}+R(u)=-m\ddot{y}_0 \quad , \tag{15}$$

where $u, \dot{u}, \ddot{u}$ are the movement, velocity and acceleration of the structure, respectively; m is the structure mass; $\gamma(u_{max})$ is the coefficient of inelastic resistance; $R(u,u_{max})$ is the system rigidity; $\ddot{y}_0(t)$ is the accelerogram of base vibrations.



a) b)

Figure 9. Dependence of the structure rigidity (a) and the coefficient of inelastic resistance of the structure (b) on the maximum displacement over the structure loading history.

The integration of equation (15) has been carried out by standard methods. If the characteristics of the system change within the integration step, its parameters change in accordance with the change in these characteristics. As a result, it is possible to obtain the dependences of the final (after seismic impact) period and the system damage coefficient on the initial period of its oscillations, i.e. period and damage spectra of the system. Fig. 10 and 11 show examples of such spectra for the Bucharest and Tabas earthquakes.

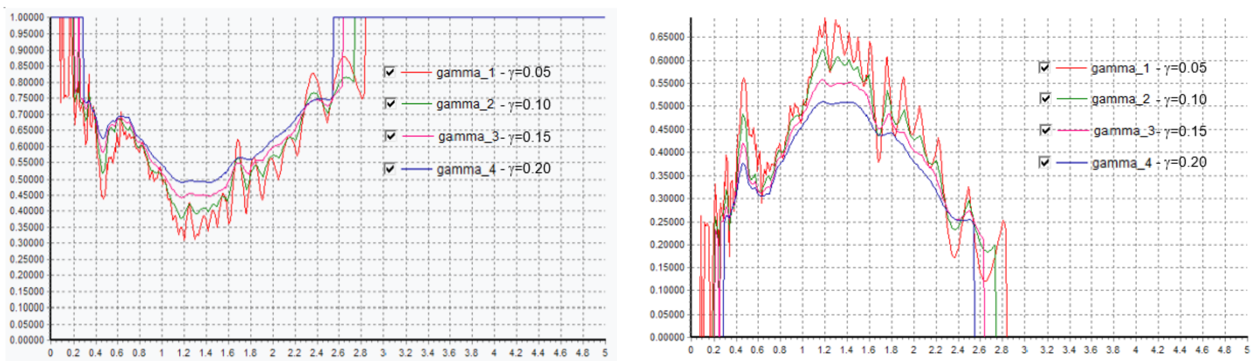


Figure 10. Spectrum of periods (left) and damage spectrum (right) for the Bucharest earthquake for f = 0.25.

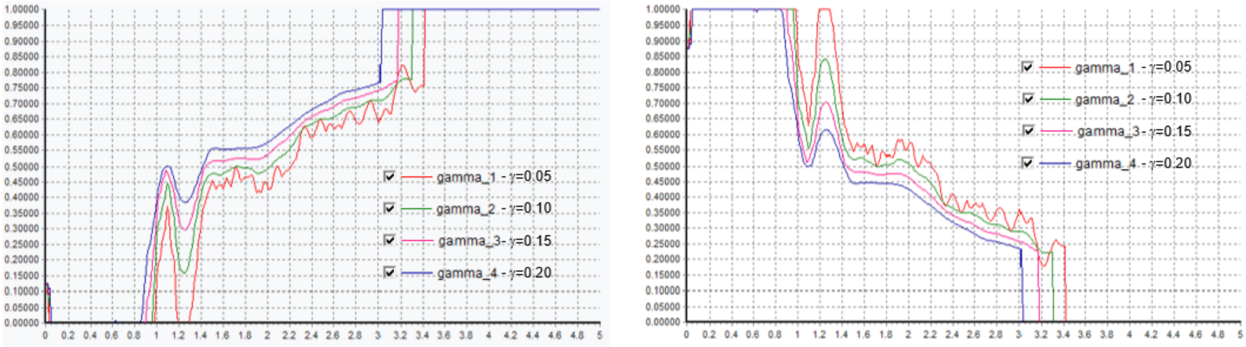


Figure 11. Spectrum of periods (left) and damage spectrum (right) for the Tabas earthquake for *f* = 0.25.

As can be seen from the figures, the systems under consideration with the accepted characteristics of damage accumulation must survive the Bucharest earthquake without collaps, and in the case of the Tabass earthquake, all structures with periods ranging from 0.05 to 1 s must be destroyed.

3. Results and Discussion

When modeling seismic impacts, it is necessary to take into account their characteristics discussed above. The importance of certain characteristics is determined by the adopted limit state. As it is known, the transition to multi-level designing is currently underway. As minimum, two levels of ultimate state and two levels of seismic input are considered. The first limit state is a violation of normal operation, which is referred to as SLS (Serviceability Limit State). It is allowed once every 50–300 years and after it the structure keeps working as usual. The corresponding earthquake is called a design one (DE).

The second limit state is damage accumulation, incompatible with further operation – ULS (Ultimate Limit State). It is allowed with repeatability once every 500–5000 years. It corresponds to the maximum design earthquake (MDE). The requirements for multi-level designing are available in Eurocode-8. In a number of countries, for example, in Italy and France, these requirements are detailed. They provide for four limit states (4 action levels). The first limit state is the complete absence of damage (DLS (Damaged Limited State)), which can take place once every 21 years. The second limit state is SLS which can take place once every 60 years.

The third limit state is ULS with a repeatability of once every 500 years. And the fourth limit state is CLS (Collapsed Limited State) with a repeatability of once every 700 years.

For each limit state and its corresponding actions, different factors are important. For calculating structures using the DLS and SLS, the PGA value should be decisive. The larger the PGA, the greater the structure strains. It goes without saying, the model action should be resonant, i.e. the prevailing action frequency should coincide with the peak of the amplitude-frequency characteristics of the structure. If the system is non-linear, for example, a seismically isolated building on kinematic supports, the PGA value is to correspond with the oscillation period according to the technique proposed in [26].

In all cases, it is necessary to take into account the significant dependence of the PGA and κ on the prevailing input period, which decreases 3–5 times with an increase in the oscillation period from 0.2 to 2 seconds. As damage accumulates, the role of the PGA decreases and energy performance becomes important. Here, from the authors' point of view, preference should be given to I_A and CAV parameters, since they do not depend on the prevailing input period. Values such as, for example, SED, significantly depend on the prevailing input period, which at the input generation it should be adjusted to the fundamental period of the structure oscillation. However, during the accumulation of damages, the period of oscillation falls, and the question of tuning for the period becomes problematic. In our opinion, the problem can be sold using the spectra of plastic deformation forces and the damage. The choice of spectrum depends on the mechanism of structure damage accumulation. For metal structures and other structures that are characterized by plastic work, the tuning is based on the work of plastic deformation forces. For stone and reinforced concrete structures, crack formation and damage accumulation according to the Kirikov-Amankulov model are typical. In these cases, the prevailing input period should correspond.

4. Conclusion

The analysis of seismic action properties allows us to conclude the following:

1. It seems possible to use the simplest seismic impact models for typical designing and calculating mass construction objects.

Such models are also useful at the preliminary design stage, when the required amount of seismological data is not available yet. These impact models may be unlike the real ones, but they must ensure that the basic characteristics of the calculated models and the real impacts are consistent each other.

2. In structure calculating under the action of DE, when the structure has no damages, the most important characteristics are kinematic ones.

For most structures, first of all it is necessary to consider the values of PGA and harmonic coefficient. They determine seismic loads on the structure. In this case, the resonant actions should be chosen for the structure. The most important requirement is the observance of the dependence of both PGA and κ on the prevailing period. The larger the period, the lower the PGA and κ values. Dependences PGA (T) are available in both scientific and educational literature; the dependence $\kappa(T)$ is given in this paper.

3. In calculating the action of moderate earthquake or MDE, when damages appear in the structure and the deformation diagram becomes non-linear, the energy characteristics of the impact become important. The authors believe that in these cases the most convenient are Arias intensity and cumulative absolute velocity (CAV), since these characteristics are independent of the prevailing input period.

4. The authors propose two characteristics important, in their opinion: they are the spectrum of the work of plastic deformation forces and the damage spectrum. Peaks in the spectra of the model input should correspond to the fundamental periods of the structure oscillations.

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